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Procedia Computer Science 159 (2019) 2294–2303

Procedia Computer Science

www.elsevier.com/locate/procedia

23rd International Conference on Knowledge-Based and Intelligent Information & Engineering Systems

The fuzzy TOPSIS applications in the last decade

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Abstract

Multi-criteria decision-analysis (MCDA) methods have been widely applied by many researchers in various fields of study. One of the numerous MCDA methods, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) under fuzzy environment, namely fuzzy TOPSIS, has been successfully applied in many practical, real-world challenges. This paper provides a short review of fuzzy TOPSIS applications. The research is based on 25 studies conducted in the years 2009 - 2018. Most relevant and most cited papers concerned with fuzzy TOPSIS technique were analyzed and categorized into application areas, such as supply chain, environment, energy sources, business, healthcare. Fuzzy TOPSIS implementations are examined and compared by approaches used, such as fuzzy sets, hesitant fuzzy sets or intuitionistic fuzzy sets, by other methods combined with fuzzy TOPSIS, such as fuzzy Analytic Hierarchic Process (AHP) or enhancements for group decision-making and by a number of alternatives and criteria used. Finally, insights into ongoing trends, most popular approaches, and directions of study concerning the fuzzy TOPSIS method are presented.

Peer-review under responsibility of KES International.

Keywords: fuzzy TOPSIS; review; multi-criteria decision-analysis; MCDA;

1. Introduction

Numerous multi-criteria decision-analysis (MCDA) methods have been developed in order to solve various decision problems in a broad range of areas. Since the 1960s, MCDA has been applied in many real-life problems, with application fields ranging from green supply chain management [1, 2], logistics [3, 4, 5] or engineering and manufacturing systems [6, 7, 8] to health, environment management and sustainable development [9, 10, 11, 12], to name a few. MCDA methods have been proven successful in challenging such complex multi-criteria problems by many researchers [13, 14]. In recent years, a lot of attention has been given towards both the practical implementations of

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1877-0509
10.1016/j.procs.2019.09.404

existing MCDA methods and towards improving, enhancing or comparing available ones [15]. Studies using MCDA approaches often deal with the selection of the preferred alternative among other alternatives, creation of the alternatives' ranking or sorting of the alternatives. Moreover, many MCDA methods are enhanced and adapted for the use of the fuzzy logic [16, 17], which later applied to real-world problems, effectively deals with the conditions of incomplete knowledge or cases where values are often expressed by linguistic variables rather than by exact values [18, 19, 20, 21].

One of the most popular MCDA methods is a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), developed by Hwang and Yoon [22]. By its simplicity, computational efficiency and comprehensive mathematical concept, it has been thoroughly adopted in many use cases. The extension of the classical TOPSIS method with regard to fuzzy logic, namely fuzzy TOPSIS, has been also successfully implemented in various application areas [23, 24, 25]. Similarly, as classical TOPSIS method, the fuzzy variant has received much interest from researchers and gained a lot of popularity. Comprehensive studies were conducted with regard to TOPSIS method, e.g. an extensive overview of practical implementations of TOPSIS method conducted by Behzadian et al. [26], who analyzed 266 studies from more than 100 journals since the year 2000. However, this review was conducted in 2012, hence it does not include the most recent works. Not only the TOPSIS method but also other MCDA techniques were gathered and analyzed in the two-decade study by Mardani et al. in 2014 [27]. Another literature review was conducted by Kahraman et al. in 2015, but it regards only the use of fuzzy MCDA methods' variants [28]. Researchers also studied the group decision-making with the TOPSIS method [29]. In many cases, however, research has been refined to specific application areas, such as an overview of renewable energy sources or economics, which could be found in [30, 31].

In this paper, the overview of the implementation of fuzzy TOPSIS methods is analyzed. The 25 articles and studies from the last decade (years 2009-2018) are examined and compared. Uses of variants of fuzzy TOPSIS regarding surveyed literature, such as hesitant fuzzy TOPSIS or intuitionistic fuzzy TOPSIS are outlined. Moreover, this paper provides insights into ongoing trends regarding the use of fuzzy TOPSIS, its most common application areas and practical problems solved.

The rest of the paper is organized as follows. The next section presents the analysis and comparison of fuzzy TOPSIS implementations during the previous decade. The last section outlines current trends, summarizes made comparisons and conclusions, and finally outlines potential future directions.

2. The fuzzy TOPSIS applications

Table 1. presents the 25 selected scholarly papers concerning the implementations of fuzzy TOPSIS technique. The papers were selected only from the years 2009 - 2018 included. They were chosen based on their relevance with the investigated topic, their citation numbers, and popularity. As the fuzzy TOPSIS technique was used in a broad variety of real-world applications, the main application area is outlined, as well as a brief description of the multi-criteria decision problem, dealt in a given study. Apart from sorting by the year of publication, this set of papers does not have a strict order.

Table 1: Overview of selected articles concerning fuzzy TOPSIS

No.	Title of paper	Area	Problem description	Year	Ref.
1	A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method	Supply Chain Management	An automotive company is desired to select the most appropriate supplier for one of the key elements in its manufacturing process	2009	[32]
2	Fuzzy hierarchical TOPSIS for supplier selection	Supply Chain Management	This section applies the fuzzy hierarchical TOPSIS to thelithium-ion battery protection IC (LI-BPIC) supplier selectionproblem.	2009	[33]
3	Weapon selection using the AHP and TOPSIS methods under fuzzy environment	Defence Industry	Weapon selection problem - rifle	2009	[34]

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No.	Title of paper	Area	Problem description	Year	Ref.
4	Project selection for oil-fields development by using the AHP and fuzzy TOPSIS method	Energy	Project selection for oil-fields development for National Iranian Oil Company	2010	[35]
5	A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods	Performance Evaluation	Evaluate the performance of global top four notebook computer ODM companies	2010	[36]
6	A new TOPSIS-based multi-criteria approach to personnel selection	Personel Selection	A branch office of a multinational IT firm A, wanted to recruit a CIO externally, since the previous one moved to the Headquarters.	2010	[37]
7	Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea	Environment	Identifying the best alternatives in cases of management of accidents with oil spill in the sea.	2011	[38]
8	Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology	Energy	Selection of the best energy technology alternative	2011	[39]
9	A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers	Supply Chain Management	Choosing green supplier for Ford Otosan company	2012	[40]
10	A utility-based fuzzy TOPSIS method for energy efficient network selection in heterogeneous wireless networks	Networks	Energy efficient network selection in heterogeneous wireless networks	2012	[41]
11	A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry	Healthcare	Web based/electronic service quality concept, Hospital web sites	2012	[42]
12	Hesitant fuzzy multi-attribute decision making based on TOPSIS with incomplete weight information	Energy	Energy police selection (energy projects)	2013	[43]
13	A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach	Supply Chain Management (green)	Sustainable supply chain initiatives and examines the problem of identifying supplier selection operations in supply chains	2013	[44]
14	Integrated fuzzy multi criteria decision making method and multiobjective programming approach for supplier selection and order allocation in a green supply chain	Supply Chain Management (green)	Iranian automobile manufacturers, suppliers of this case study provide a specific product which is used as a trim part of the automobile	2013	[45]
15	A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection	Supply Chain Management	A manufacturer of transmission cables for motorcycles needs to select a supplier of metallic components used in a variety of transmission cables.	2014	[46]
16	Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies	Construction	Construction projects selection and risk assessment at King Abdulaziz University (KAU)	2014	[47]

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No.	Title of paper	Area	Problem description	Year	Ref.
17	Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company	Supply Chain Management (green)	Selecting green suppliers for a Brazilian electronics company	2014	[48]
18	The inclusion-based TOPSIS method with interval-valued intuitionistic fuzzy sets for multiple criteria group decision making	Healthcare	Medical decision-making problem concerning basilar artery occlusion, treatment methods of acute cerebrovascular disease	2015	[49]
19	Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey	Energy	Ranking renewable energy supply systems in Turkey	2015	[50]
20	A framework for water loss management in developing countries under fuzzy environment: Integration of Fuzzy AHP with Fuzzy TOPSIS	Environment	Real water distribution system in a developing country by engaging policy makers and affected stakeholders. Case study of Nablus Water Distribution System (NWDS), Palestine	2016	[51]
21	A fuzzy TOPSIS and Rough Set based approach for mechanism analysis of product infant failure	Manufacturing	Case study of analyzing car infant failure about body noise vibration harshness complaint	2016	[52]
22	An extension of fuzzy TOPSIS for a group decision making with an application to tehran stock exchange	Stock exchange	Ranking of seven automotive and automotive parts manufacturing companies in the Tehran Stock Exchange (TSE) for investment.	2017	[53]
23	Evaluation of sustainable acid rain control options utilizing a fuzzy TOPSIS multi-criteria decision analysis model frame work	Environment	Sustainable acid rain control options in Niger delta region	2017	[54]
24	An extended intuitionistic fuzzy TOPSIS method based on a new distance measure with an application to credit risk evaluation	Business	Credit risk evaluation for strategic partners	2018	[55]
25	An interval type-2 fuzzy TOPSIS model for large scale group decision making problems with social network information	Business	Illustrative example of IT-2 fuzzy TOPSIS on selecting restaurant based on the given network structure	2018	[56]

As seen in the Table 1, the fuzzy TOPSIS was applied in many practical use cases, starting from selecting a proper supplier for manufacturing, through assessment of services quality and ending at selection and ranking of the renewable energy sources, proving that is extensively implemented in a wide range of real-world problems. The most common topic of fuzzy TOPSIS applications, outlined in this paper, definitely supplies chain management. Considering it, very common implementation regards the green supply chain and sustainable solutions. Additionally, the popular challenge tackled by fuzzy TOPSIS is both the energy policies selection and ranking of the renewable energy sources. Hence, there is a growing popularity of TOPSIS researches regarding the problems, which take into consideration sustainable development, environment, and renewable energy sources. Another area, which received the attention of researchers in the healthcare industry, with such problems as choosing proper treatments, e.g. in acute cerebrovascular disease [49].

In Table 2, a summary of the given application areas is presented with the numbers of implementations per category. The other categories, not outlined in the summary table as they only have one implementation per category are personnel selection, networks, construction, manufacturing, and stock-exchange. Many practical problems require not only the detailed comprehension of a given use case but also the expert's knowledge. However, often one expert

is not suitable for the complexity of the investigation and the knowledge of the group of experts is necessary. When determining e.g. either criteria or the weights of the criteria, proper group decision making is an important step in order to minimize the errors concerned with human failure [57]. Thus, in many mentioned implementations of fuzzy TOPSIS (nearly half of the 25 papers), group decision-making steps had to be conducted.

Table 2: Number of implementations in a given category.

Application area	Number of implementations
Supply Chain Management	8
Environment & Energy	4
Energy	3
Healthcare	2
Business	2
Other	5

Table 3 depicts the overview of the types of fuzzy TOPSIS method used in examined papers. Furthermore, other methods that were used in combination with the TOPSIS technique are presented. Table 4 presents the total number of occurrences of a given method type in investigated implementations. Without a doubt, the most common method is the classical fuzzy TOPSIS based on the fuzzy sets, used 19 times out of 25. However, researchers seek to enhance and change the classical approach in order to comprehensively deal with MCDA problems. Hence, variants of the classical fuzzy approach with regard to the TOPSIS method were introduced. The most popular variant is the intuitionistic fuzzy TOPSIS, based on the intuitionistic fuzzy sets (IFS), with 3 implementations. One of them is based on interval-valued intuitionistic fuzzy sets (IVFS), since the problem dealt with conditions of incomplete knowledge [55]. Also, hesitant fuzzy sets (HFS) were used in the hesitant fuzzy TOPSIS method, 2-type fuzzy TOPSIS based on the interval type-2 fuzzy sets and the fuzzy hierarchical TOPSIS. One interesting fact that requires emphasis is the popular adoption of the Fuzzy Analytic Hierarchy Process (AHP) method in order to determine the criteria weights, used later in the TOPSIS method. Many real-world problems, when tackled with MCDA approach, have a lot of different criteria, which often have a different significance. Proper examination of their weights is a vital point of the TOPSIS method, as it can greatly influence the final preference ranking. The fuzzy AHP method has been proven effective in criteria weights calculations, hence such popularity [58]. In the examined implementations of fuzzy TOPSIS, fuzzy AHP method has been used eight times.

Table 3: Review of the types of the fuzzy TOPSIS method used among with other strategies.

No.	Type of main method used	Other methods and strategies used	Group decision-making
1	intuitionistic fuzzy TOPSIS	intuitionistic fuzzy sets	•
2	fuzzy hierarchical TOPSIS	fuzzy sets, metric distance method	
3	fuzzy TOPSIS	fuzzy sets, fuzzy AHP method	•
4	fuzzy TOPSIS	fuzzy sets, fuzzy AHP method	•
5	fuzzy TOPSIS	fuzzy sets, fuzzy AHP method	•
6	fuzzy TOPSIS	fuzzy sets, TOPSIS with veto threshold	•
7	fuzzy TOPSIS	fuzzy sets, enhanced method for group-decision making	•
8	fuzzy TOPSIS	fuzzy sets, criteria are determined by fuzzy pair-wise comparison matrices	•
9	fuzzy TOPSIS	fuzzy sets, DEMATEL, fuzzy ANP	
10	fuzzy TOPSIS	fuzzy set representation utility (FSR) for TOPSIS	
11	fuzzy TOPSIS	fuzzy sets, fuzzy AHP	

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No.	Type of main method used	Other methods and strategies used	Group decision-making
12	hesitant fuzzy TOPSIS	hesitant fuzzy sets, optimization model based on the maximizing deviation method, which can be used to determine the attribute weights	
13	fuzzy TOPSIS	fuzzy sets, Triple Bottom Line (TBL) approach (economic, environmental, and social aspects)	
14	fuzzy TOPSIS	fuzzy sets, fuzzy AHP	
15	fuzzy TOPSIS	fuzzy sets, comaprison of fuzzy TOPSIS with fuzzy AHP	•
16	fuzzy TOPSIS	fuzzy sets, fuzzy AHP	
17	fuzzy TOPSIS	fuzzy sets, geometric mean based fuzzy TOPSIS, proposed fuzzy TOPSIS (aggregation method changed)	
18	intuitionistic fuzzy TOPSIS	interval-valued intuitionistic fuzzy sets, method based on IVIFSs	•
19	fuzzy TOPSIS	fuzzy sets, Interval Shannon's Entropy (criteria weights)	
20	fuzzy TOPSIS	fuzzy sets, fuzzy AHP	•
21	fuzzy TOPSIS	fuzzy sets, rough sets	
22	fuzzy TOPSIS	fuzzy sets, fuzzy A-TOPIS, C-TOPSIS, M-TOPSIS	•
23	fuzzy TOPSIS	fuzzy sets,	•
24	intuistutionic fuzzy TOPSIS	intuitionistic fuzzy sets, proposed distance measure method	
25	interval type-2 fuzzy TOPSIS	interval type-2 fuzzy sets, SNA community detection method	

Table 4: Number of implementations with respect to the type of the fuzzy TOPSIS used.

Method type	Number of implementations
classical fuzzy TOPSIS	19
intuitionistic fuzzy TOPSIS	3
hesitant fuzzy TOPSIS	1
2-type fuzzy TOPSIS	1
fuzzy hierarchical TOPSIS	1
AHP method to determine criteria weights	8

Each practical implementation of fuzzy TOPSIS investigates a different set of criteria and alternatives. In Table 5, the comparison of a number of alternatives and criteria is shown. Most of the cases deal with numbers of criteria ranging from three to six criteria - 20 implementations out of 25 falls in this range. However, cases with only two criteria have been analyzed or with nine criteria. Nevertheless, this does not take into consideration the fact that some of these criteria are aggregated, meaning that although only 3 are used in the TOPSIS method, these three criteria are obtained from an additional set of criteria. This is done e.g. in [54] where $C_1 - Sustainability$ criterion, examines several sub-criteria, such as cost-effectiveness, environmental competence, quality, reliability, vulnerability, green design or respect for policy. The alternatives vary greatly from one another, sometimes only three or four alternatives are considered, as in [45, 41] or even 30, as in [47].

Table 5: Comparison of the number of alternatives and criteria.

No.	Number of criteria	Aggregated Criteria	Number of alternatives
1	4	×	5
2	3	✓	4
3	6	×	5
4	6	×	5
5	6	×	4
6	11	×	5
7	2	×	10
8	9	×	7
9	5	×	4
10	3	×	3
11	6	✓	13
12	4	×	5
13	3	✓	4
14	5	✓	3
15	5	×	5
16	5	×	30
17	4	×	12
18	5	×	4
19	9	×	4
20	5	×	5
21	5	×	14
22	8	×	7
23	3	✓	10
24	5	×	5
25	4	×	5

3. Conlusions

Performing the review of the literature concerning the TOPSIS method under fuzzy environment is an important step in identifying current and emerging trends of this area. This paper analyzed most popular articles from the years of 2009 - 2018 with regard to fuzzy TOPSIS implementations. Application areas were categorized in order to distinguish common fields of interest, such as supply chain management, environment-friendly solutions, energy industry or business. However, the fuzzy TOPSIS was used in a very broad spectrum of areas, with implementations in the defense industry, such as weapon selection or in healthcare, such as proper treatment selection. The classical fuzzy TOPSIS technique based on fuzzy sets was used most frequently, however, its more complex variants using intuitionistic, hesitant or 2-type fuzzy sets were also effectively implemented in more complex scenarios. In cases with incomplete knowledge interval based fuzzy sets were used. Group decision-making is a vital point of a fuzzy TOPSIS technique, where multiple experts influence the final decision. Group decision-making was implemented in nearly half of the examined papers Additionally, an interesting approach was the use of the fuzzy AHP method in order to determine the weights of the criteria for the fuzzy TOPSIS. For further study, it would be valuable to review more papers concerning the fuzzy TOPSIS method and compare them with different variants of this technique. Moreover, it would be beneficial to extend this study and review not only the fuzzy TOPSIS but also other MCDA methods under the fuzzy environment.

Acknowledgments

The work was supported by the National Science Centre, the grant no. UMO-2016/23/N/HS4/01931 and by the Faculty of Computer Science and Information Technology, West Pomeranian University of Technology, Szczecin statutory funds.

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